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Sound Phenomena of Deposited Snow

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Abstract

Proceeding from practical experiences in past and present times an attempt is made to analyse the acoustic behaviour of deposited snow in undisturbed as well as in disturbed state.

The surface of the snowpack is, as opposed to its behaviour as regards light waves, relatively a poor diffuse reflector of sound waves, since its inequalities correspond to the order of size of wave lengths only in special cases.

The sound waves will refract going over from the air into the snowpack, within the snowpack itself and going over from the snowpack into the air. The refractions within the snowpack occur, among effects of inflexion, at the sheets between more loosely and more densely occupied structures. Thus, they may take place more frequently in an undisturbed, many-stratified snowpack than in disturbed but with regard to their density rather homogeneous depositions of avalanches.

The depth of penetration of audible sound waves has been proved to several metres below snow surface, and even in thick avalanche depositions it may reach down to the bottom. The fact hitherto not cleared, that sounds such as cries for help or signals from out of the snowpack can not, or only seldom under determined conditions, be perceived above its surface, is in the main based on microclimatic conditioned total reflection of the sound waves at the level of colder and warmer air stratas at a small distance above snow surface. From this observation new impulses for lifesaving techniques could result.

Particular attention is paid to the release of avalanches by sound waves. The correlating analysis of kinds of sound, which are well known for releasing avalanches, shows that they have commonly a high percentage of sound waves, whose frequency lies in the upper portion of audibility. Experience has shown, that such sound waves may effect an allround fracture of parts or of the whole snowpack, if it has ripened to a degree that the fracture could occur within a reasonable space of time also by itself. The critical moment of tension within the snowpack which is necessary for the allround fracture and consequently for the formation of avalanches may be brought on and released by the sound waves through intensive disturbance of loosely occupied structures within the snowpack, during which phenomena of interference probably play an essential role. Investigations on the practical application of sound waves for the purpose of releasing avalanches are in progress.

I. Introduction

Snow research has hitherto concerned itself hardly at all with the sound phenomena of deposited snow, although many observations and much experiences are available regarding them. It therefore appears to be suitable to take up these problems again, since they can undoubtedly claim to be of scientific interest, and their solution could also be of practical importance.

II. Acoustic Bases of the Consideration

Sound waves are mechanical waves which arise through the spreading of a disturbance caused in a material periodically or non periodically, through propagation of

the waves from the generating centre from particle to particle of the material. The particles must have a stable position of equilibrium, which is imparted to them by the elasticity of the material. One therefore speaks of *elastic waves*. If the particles join with the disturbing forces and therefore remain in their shifted position, the waves do not arise at all or break down in such layers. In unelastic, *i.e.* plastic materials, no waves can therefore arise, but only in elastic, solid substances, liquids and gases. The elastic sound waves in liquids and gases are always *longitudinal*, that is to say the excited particles of the material swing to and fro harmonically in the direction of propagation of the wave. On the other hand, in elastic solid substances the sound waves may be longitudinal or transversal. *Transversal waves*, with which the separate particles of the substance solid substances swing to and fro harmonically at right angles to the direction of propagation, are to be found only in elastic, solid substances, since only these offer resistance to shearing forces, *i.e.* possess a modulus of shear which, together with the modulus of elasticity, determines their speed.

The magnitude of the *velocity of propagation* of elastic waves, the velocity of sound, depends on the temperature, pressure, elasticity and density of the substance, whereby in the same substance the velocity of longitudinal waves is also greater than that of the transversal waves. In general the velocity of sound becomes greater as the substance becomes stiffer, since stiffness signifies a denser packing of the particles and therefore more direct sensitivity to mutual movement.

When a sound wave from one substance comes against another substance on the boundary surface, and penetrates only partly or not at all into that substance, complete or partial *reflection* occurs. Thereby the reflected ray forms with the axis of incidence the same angle as the incident ray. The reflection is *diffused*, if the reflecting surface has uneven portions of the order of magnitude of the wave length, so that the several parts of the wave are reflected back in different directions.

If a sound wave passes from one substance into another in which its velocity of propagation is different, the wave indeed changes in length, but the frequency of the wave remains the same, the tone *a* for instance remains *a*. The deviation which the sound ray when passing obliquely from one substance into another substance, experiences at the boundary surface of the two substances, is termed *refraction*. If the velocity of the sound in the first substance is greater than that in the second, the sound ray is refracted towards the axis of incidence. On the contrary, the sound wave is refracted away from the axis of incidence, if the velocity of sound in the first substance is less than that in the second.

Like light waves, sound waves have the peculiarity of being bent round the corner of an obstacle placed in their path. This phenomenon, termed *diffraction*, is however only of any significance when the dimensions of the object or of an opening in it are approximately of the same order of magnitude of wave-length as the waves that meet it.

From the simultaneous interacting of two or more similar waves at one point, we have the phenomenon known as *interference*. The amplitude of the composed wave is at this point equal to the sum of the momentary amplitudes of the separate waves. Consequently if waves meet in such a manner, that there is complete or partial correspondence between wave peak and wave peak, and also between wave trough and wave

trough, the amplitude of the composed wave is greater than that of the separate waves. These therefore strengthen each other. In this way arise regular pulsations (beats), the number of which per second is equal to the difference of the frequencies of the interfering sound waves. The process itself is termed *constructive* interference. *Destructive* interference occurs when the waves meet in such a way that peak meets trough and trough meets peak. The amplitude of the composed wave is then smaller than that of the single original waves.

III. Sound and Snow Structure

It has for long been known that *sound can release avalanches* from the snow covering steep slopes which is ready to descend in a high degree. We are aware, from oral tradition and written records, that in olden days, in many Alpine districts, the church bells were rung when the danger from avalanches was very great. The bells were certainly intended to call good people together to pray for the averting of a threatened catastrophe, but in several cases the ringing was evidently done with the intention that the sound should release the dreaded avalanches at a time when their descent could be controlled. Still at the beginning of the present century, drivers passing over the Alpine passes with their sledges removed the bells from their horses' necks in order not to risk an avalanche being caused by their tinkling. Besides that, they tested the safety of critical places by cracking their whips, thus releasing gradually actual avalanches. Among skiers making tours in the Alps before the 2nd World War, it was very customary to test suspicious slopes shouting shrieking or sharp whistling. In this manner, I myself have several times succeeded in causing superficial compact-snow avalanches to come down (Krasser, 1931). Anyone who has spent some time in wintery high regions in connection with blasting operations or cannon shooting would observe that the noise alone may cause avalanches to descend. Finally, the number of avalanches released by the noise of builders machines is always increasing. Also a direct connection could be definitely established between the engine noise of jet propelled aircraft (not break-through of sonic barrier) and the descent of avalanches.

The *possibility of the release* of avalanches by sound has hitherto been regarded as trifling by eminent European snow-research workers and dismissed with the argument that the sound waves of the above mentioned sound sources exert on the snowpack a pressure that is much smaller than that caused by the slightest breath of wind, and these waves could therefore not be the factor responsible for the descent of avalanches. This objection, as thus formulated, is certainly correct in accordance with sense. But it appears to me that the case is by no means so simple.

Snow can be a sound-carrier only under the assumption that it behaves more or less elastically under the action of the sound, *i.e.* if its individual crystals or aggregates of crystals have a stable position of equilibrium and do not inevitably work together with the sound waves as disturbing force, but endeavour to return into the initial position. In this sense, pronounced bridge-structures with relatively large porous spaces appear to be more elastic than kinds of snow with few pores, which should behave more plastically. Apart from the fact that the snow structure allows of all transitions from

elastic to plastic behaviour, this behaviour will be favoured in one direction or another by the momentary amount of air and water contained in the snow. Whether the snow acts more elastically-springing or more plastically-damping, will however depend not only on its composition, but also on the type of stressing. When snow is very tough, it reacts to brief stressing with slight damping effect predominantly elastic, when it is not so tough, it reacts to static stressing with slight springing effect predominantly plastic. Regarded mechanically, therefore, the snow represents a characteristic *spring-damper system*. Therefore the most important question to be answered by snow research is the following: with regard to the propagation of mechanical waves, under what conditions does the snow behave more as an elastic substance, and under what conditions more as a plastic substance? According to past practical experience, very cold snow for instance, of great toughness, is so elastic that it transmits stresses to a great extent. On the other hand, most kinds of snow react to extremely brief shocks, such as a sharp detonation, almost without any damping, thus also highly elastically.

The following consideration may make clear what *kinds of sound-waves* can under certain circumstances cause protracted disturbance of structure in the spring-damper system of an undisturbed snowpack consisting of one or several layers. In air and water the elastic sound-waves are always longitudinal, but in solid substances they may be not only longitudinal but also transversal. In snow, therefore, one must reckon with both kinds of elastic waves. From this it has to be concluded that the sound also spreads out in the snowpack, and in fact longitudinally, if the structure behaves indeed inelastically, but contains hollow spaces filled with air or water and communicating more or less with each other. Longitudinal movement of the snow structure itself appears to be possible only when cohesion is lacking entirely (swimming snow) or to a great extent (disintegrated bridge-structures). Transversal waves, on the other hand, can be present in all elastic snow-structures which are capable of withstanding shearing stresses. It may even be supposed that by far the greater portion of the sound-waves spreading out in the snow consists of transversal waves. From this it results that snow structures may be broken up by the *concerted action of longitudinal and transversal waves*. These, however, do not spread out uniformly, but are, even in the simplest case, many times reflected, refracted, bent, and strengthened or weakened by interference, and thus on the whole more or less damped. Whether the *disturbing of the structure* by sound-waves leads to collapse of the structure depends on the composition of the snow and on the magnitude of the force acting on it. The *causes of collapse of a structure* have probably to be sought in the attrition of the structure by over-stressing of its shearing strength by transversal wave-motion, and in the rapid change of over-pressure and under-pressure caused in the pore system by longitudinal waves (Krasser, 1964, pp. 11-12 and 33).

The question has still to be explained, what *frequencies* the sound-waves have which spread almost undamped in the different kinds of snow, penetrate in the snowpack through elastic spring-transmission right to the zones of greatest stressing, and there cause collapse of structure. Nevertheless, some valuable indications are already available. Thus Kay and Evans (19..?) could show, that within the talking range of 125 to 4 000 cycles per second cold new snow absorbs noise with higher frequencies considerably more strongly than noise with lower frequencies. And through the investigations of

Bogorodskii and Dobrotin (1963) we know that the velocity of longitudinal and transversal waves, as well as Poisson's ratio, Young's modulus and shearing modulus increase very uniformly with the density of fresh snow that has been hardly or only slightly metamorphosed, and in the case of vertical and horizontal spreading, show only slight differences. Certainly, when the snow has undergone the inevitable metamorphosis due to ageing, the velocity of sound vertical to the stratification reaches about double the value of the velocity parallel to the stratification. According to the available measurements, the vertical velocity of longitudinal sound-waves in cold fresh snow (density 0.242 g/cm^3) amounted to 360 m/sec , whilst in artificially pressed cold snow (density 0.527 g/cm^3) it was 1750 m/sec . On the average, the vertical velocity of transversal waves was about 38% lower than that of the longitudinal waves.

From the results of the investigations cited, it can with a few reservations be deduced that relatively high-frequency short-wave sound will be absorbed by snow of lower density more strongly, but by snow of great density less strongly, than relatively low-frequency sound. With this the experiences mentioned at the start agree well, in so far that the kinds of sound which lead to the rupture of relatively dense masses of snow ready to descend, and release avalanches, have a considerable share of their frequencies in the *upper range of audibility* and also still higher.

The *practical aim* of the current investigations is to discover whether it would be possible, with a suitable sound-producer, to direct sound onto snow coverings from above or below and thus release avalanches prematurely and bring them down under control. This method would be of great importance in all cases where slopes threatened with avalanches have to be rendered safe and the use of explosives is not advisable or impossible.

IV. Audibility within and outside the Snowpack

Persons who have been taken alive from an avalanche, have stated time and again that, as long as they were conscious under the snow, they could hear the voices of their rescuers and the noises made by tools and engines even at depths of several metres. All the greater then is their astonishment, and even dismay, on learning that their cries for help had not been heard by their rescuers. Not even four revolver shots which a man buried under the snow of an avalanche had fired, were heard by the rescuers (Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch/Davos, 1963). This peculiar phenomenon, which at first leads to the supposition of a certain irreversibility of the spreading of the sound in snow, has indeed hitherto been often discussed but as far as I know has not yet been the object of any interpretation, or even of investigation.

In the case of an *undisturbed snowpack*, consisting entirely or only superficially of fresh snow, it may be that sound entering from the outside may be already fully absorbed at a depth of 10 to 20 cm. Sound rays, however, which fall obliquely into a less absorbent, undisturbed multi-layer pack of old snow spread quicker downwards in this with the increasing density of the snow. At the boundary surfaces from the less dense to the denser layers they are refracted away from the axis of incidence, but at the boundary surfaces from the denser to the less dense layers, somewhat in the neighbourhood of the lower portion of the stratigraphic profile, they are refracted towards the

axis of incidence. The same path, but in the opposite direction, is followed by sound rays which spread upwards from the very bottom, or from any point whatever within the snowpack. Of course this spreading, in one direction as well as in the other, is dominated not only by refractions, but is also damped by reflections, diffractions and interferences. But since these phenomena occur in one and the same ray-path in each direction in the same manner, within the snowpack the audibility of a similar sound which starts from two points lying on the same ray-path, is the same at the point momentarily lying opposite.

In general, however, in the *snow deposited by an avalanche* there will be found little sign of stratification; in a certain sense it is more homogeneous than an undisturbed multi-layer pack of old snow. This does not however at once signify that the spreading of sound in it experiences less damping. The extent of the damping depends essentially on the macrostructure of the avalanche-snow, for instance on the amount of balling in the case of wet snow. The audibility within the deposited snow of the avalanche is, however, the same as in the undisturbed snowpack.

The *spreading of the sound in the snowpack* is accordingly not irreversible, but with certain restriction is decidedly *reversible*. Further it must be noted that the *audibility* within the snowpack of a sound coming from above from the outside, may be *very good* down to a depth of several metres, at least in relatively dense kinds of snow. The *origin of the inaudibility* of a sound issuing from the snowpack into the air must therefore be sought for *outside the snowpack*. I have come onto the *way to the solution* of the present problem by the sound-effect of air inversions in space, in which the sound produced by more or less remote sources of sound (for instance railway, church bells) and otherwise inaudible or only weakly audible, is rendered clearly audible through partial to complete reflection at the boundaries of colder air-masses below and warmer air-masses above. The velocity of sound in air at 0°C is namely about 331 m/sec, increases by about 0.14% per degree centigrade, consequently attaining about 340 m/sec at 20°C for instance. In this way the sound-waves are refracted away from the vertical at the momentary higher and warmer layers of air, until under circumstances total reflection occurs at a certain height above the ground.

It may be assumed as known, that also in the micro-climatic region over the snowpack a *temperature-inversion* of the air is frequently present. In this case, in dependence on the snow-temperature and irradiation, there are to be found immediately above the snow-surface generally pronounced layers of cold air, which at medium altitudes in the Alps have seldom a total thickness of more than 20 to 50 cm. Above that there follow increasingly warmer layers of air. At their boundary surfaces, *sound-waves* issuing from the snowpack are refracted away from the vertical, whereby it will generally come to *total reflection* already at a slight height above the surface of the snowpack (Krasser, 1964), so that the sound can no longer be heard by a person standing upright.

Whether the region be large or small, the sound-effect of the inversion is subject to the *influence of wind*, especially if its velocity is different at different altitudes. If the velocity of the wind is lower at ground-level than at higher altitudes because of friction with the ground, a sound directed against the wind will be refracted upwards, whilst if the sound is spreading in the same direction as the wind it will be refracted

downwards. From this it follows that when cold air flow down onto the inclined surface of snow, sound issuing from the snowpack can be heard, if at all, more distinctly uphill from its position of exit, than downhill from that place.

Trials made with the world-famous avalanche search-dog Ajax of the Austrian "Bundesgendarmerie" have shown impressively, that a tone coming continuously out of the snowpack could generally only be heard by the animal up to a slight height above the surface of the snow. When the dog noticed the tone when nosing in the surface of the snow, it instinctively threw up its head and pricked up its ears. Disappointed at not hearing anything more in spite of that, he started nosing in the snow again and the tone was there once more. But the animal threw its head up again, looked about him in wonder, and started the nosing work again. Finally, the search-dog, thoroughly confused, laid himself flat on the snow and, sniffing and attentively listening, he rowed on all fours to the point above the buried source of the continuous tone.

Because of the very small prospect of being able to locate by acoustic means a person who is crying for help under a snowpack, the attempt to design an exclusively acoustic probe may hardly be justified, because of the particulars given above. It may, however, be worth while trying to design a *combined acoustic and electromagnetic probe*, in order to have a further possibility of discovering and saving a still-living person buried under the snow of an avalanche.

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